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EVALUATION OF A SEMI-MICRO ANALYTICAL BALANCE TO PERFORM ON-FILTER DETERMINATION OF DUST MASS

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ELLIOT LAKE LABORATORY

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by

S. Hardcastle*

ABSTRACT

Accurate and precise measurement of on-filter dust masses is extremely important in assessing worker exposure to respirable solids such as quartz and Respirable Combustible Dust (RCD).

For the normal weighing range of filters at Elliot Lake Laboratory a Mettler AE 163 semi-micro electronic balance has been appraised; linearity was ± 0.011 mg, standard error was ± 0.01 mg, and agreement with a Cahn electronic balance was ± 0.02 mg.

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ÉVALUATION D'UNE SEMI-MICROBALANCE POUR FAIRE LA DÉTERMINATION SUR FILTRE DES AMAS DE POUSSIÈRE

par

S. Hardcastle*

RÉSUMÉ

L'obtention de mesures justes et précises des amas de poussière sur filtre est extrèmement importante dans la détermination de l'exposition des travailleurs aux solides respirables tels le quartz et la poussière combustible respirable (PCR).

On a évalué les mesures obtenues d'une semi-microbalance électronique Mettler AE 163 afin d'établir l'échelle de pesée normale pour les filtres situés au Laboratoire d'Elliot Lake; la linéarité était donc de $\pm$ 0,011 mg, l'erreur type de $\pm$ 0,01 mg et la conformité avec les mesures d'une balance électronique Cahn était de $\pm$ 0,02 mg.

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INTRODUCTION

A Mettler AE 163 semi-micro electronic analytical balance is available at the Elliot Lake Laboratory facility. The prime intended use of this balance is for on-filter determination of dust mass as collected by various dust samplers. This unit has been checked for precision, repeatability and accuracy, and compared against two existing balances for correlation.

The new Mettler balance is intended to replace an older Mettler Gramatic manual counter-weighting balance. This latter unit has been relegated to spare/back-up status. The new balance has provided greater precision, reduced weighing man-hours and has the facility of computer interfacing which would reduce data transfer errors. The position of the balance in an automated XRD analysis facility to measure on-filter quartz is shown in Fig. 1.

THE METTLER AE 163 BALANCE

The AE 163 is a dual-range balance with weighing ranges: 0-31 g to 0.01 mg precision, and 0 to 162.0 g to 0.1 mg precision. For both ranges it has a 100 g $\pm$ 0.2 mg built-in calibration weight. Calibrating and changing ranges of the balance are easily performed; the 31 g range, however, will be predominantly used for weighing dust filters.

The AE 163 also includes three integration time settings and two stability detector settings, excluding off. The automatic stability detector (ASd) provides an added measure of reliability to results, Step 1 (ASd-1-)* gives the greatest sensitivity. The integration time for the 31 g range can be configured to 3, 6 and 12 seconds, Step 1 (Int-1-)* being the shortest. The balance has been set up with the shortest integration time and greatest

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*These are the balance displays.

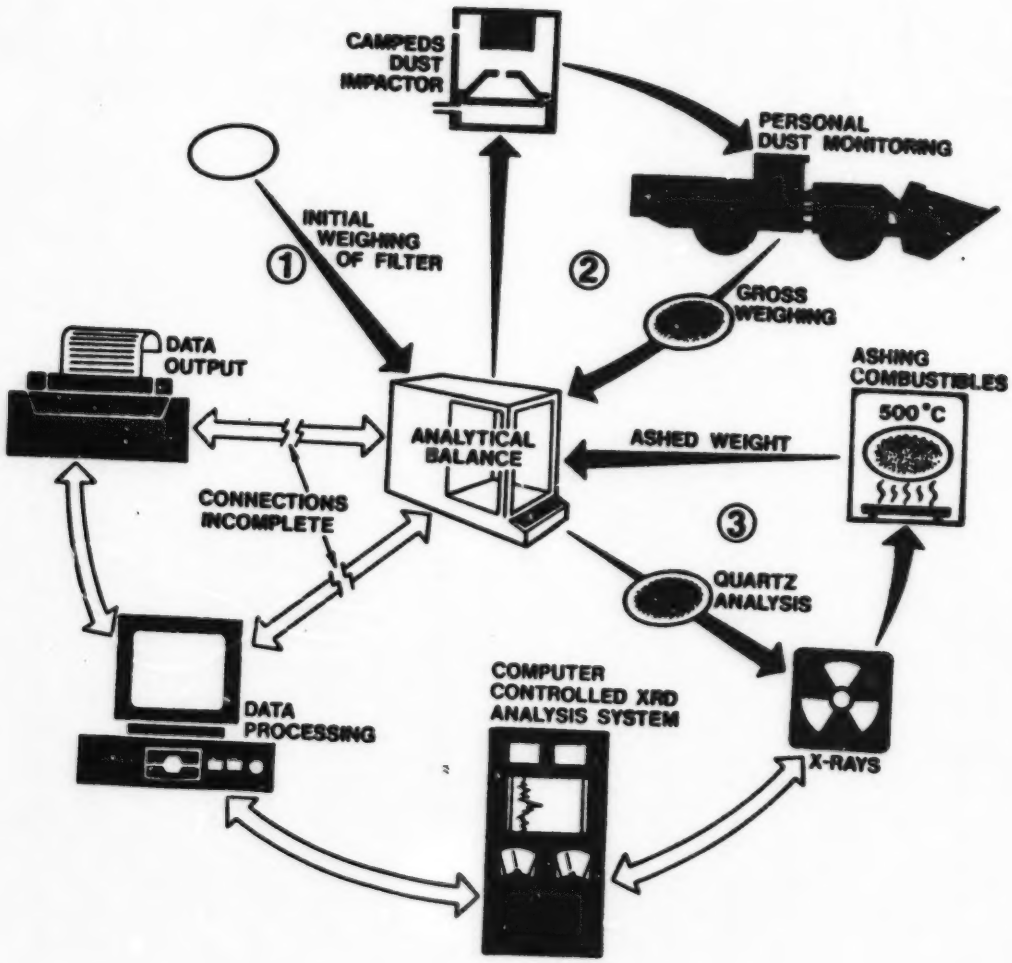

Fig. 1 - Elliot Lake Laboratory on-filter analysis for respirable solid particulates.

sensitivity. This configuration will show how stable and reliable are the internal electronics and displayed results. Generally, for normal weighing, the best accuracy is achieved with the longest integration time (Int-3-).

OPERATING ROUTINE

The location of the balance is stable, vibration free and out of direct sunlight; its environment is free from draughts and temperature fluctuations.

Beyond these general considerations the balance can be affected by static charges, pressure changes and very small draughts around and in the weighing enclosure. Static is eliminated by a uranium ore sample which ionizes the air. Pressure fluctuations due to door opening and closing are avoided with the unused side-door left very slightly ajar. Draughts are reduced by using the supplied draft shield. It may be necessary to increase the height of this shield.

The balance does not need any warm-up period unless disconnected from the mains supply; normally it is in a state of readiness. For weighing, the balance should be tared for 'zero' prior to each weight. This is necessary because of fluctuations of the resistance and hysteresis in the electronics. Occasionally taring may be required more than once to obtain the zero as the balance takes up to 30 seconds to stabilize after a weighing, depending on its magnitude. Similarly, 20-30 seconds are required to allow the balance to stabilize on weighing-in.

This procedure has been found to give the most consistent results.

CALIBRATION TESTING

Two series of calibration tests were performed using a 1 mg to 30 mg set of 'S' class weights and regularly used calibration weights:

A precision and repeatibility test purely on the AE 163.

A comparison between the AE 163, Cahn Electrobalance and Mettler Gram-atic.

In both series of tests, standard deviations, linearity and correlation coefficients are determined.

TEST SERIES I - AE 163 PRECISION, LINEARITY AND REPEATIBILITY

The first test series results are contained in Tables 1 and 2. There were 18 tests over 1 week, using 19 test weights. The series comprises 3 modus operandi:

Tests 1-12, with taring to zero between each weighing, as recommended.

Tests 13-15, taring to zero only on drift and applying drift corrections.

Tests 16-18, no taring and applying drift corrections.

Table 2 contains the results of all Tests, 1-18, and similar to Table 1, means, standard deviations, etc.

Throughout the tests various tares were used, such that the balance could be checked throughout its weighing range. The taring weights are given in both tables. For tare weights in excess of 500 mg it was necessary to complete the weighing range with zero tare weight to avoid exceeding the 31 g maximum weight.

From Tables 1 and 2, it is apparent that the mean weights disagree with the nominal weight standard; the deviations though small at the lower end of the weighing range exceed 0.1 mg at 10 g and above.

Table 3 lists the tolerances on the nominal weights in accordance with NBS for both S-class weights and the means from Tables 1 and 2. Also listed are the corresponding means for the nominal weights using the Cahn Electrobalance.

The mean weights from the tests exceed the nominal weight and tolerance

Table 1 - Evaluation of Mettler balance with repeated taring after each weighing.

Ref. Weight (mg)	Date of Calibration, Balance Weight (mg) and Deviation from Mean (mg)												Mean and Standard Deviation $\bar{x}$ (mg), σ (mg), σ (%)	
	21/11/84	21/11/84	21/11/84	21/11/84	21/11/84	21/11/84	21/11/84	21/11/84	21/11/84	21/11/84	21/11/84	21/11/84		
1	0.99 0.01	0.98 0	0.97 -0.01	0.97 -0.01	1.00 0.02	0.99 0.01	0.98 0	0.99 0.01	0.98 0	0.97 -0.01	1.01 0.03	0.99 0.01	0.98 ± 0.01	1.02
2	2.00 0	2.02 0.02	2.00 0	2.00 0	2.00 0	1.99 -0.01	2.00 0	2.01 0.01	2.01 0.01	2.01 0	2.00 0	2.01 0.01	2.00 ± 0.01	0.50
3	2.98 0.01	2.97 0	2.98 0.01	2.97 0	2.96 -0.01	2.97 0	2.97 0	2.99 0.02	2.97 0	2.98 0.01	2.96 -0.01	2.99 0.02	2.97 ± 0.01	0.34
10	10.03 0	10.03 0	10.03 0	10.04 0.01	10.02 -0.01	10.03 0	10.04 0.01	10.05 0.02	10.03 0	10.03 0	10.03 0	10.04 0.01	10.03 ± 0.01	0.10
20	20.02 0.01	19.99 -0.02	20.03 0.02	20.00 -0.01	20.01 0	20.00 -0.01	20.02 0.01	20.02 0.01	20.00 -0.01	19.99 -0.02	20.01 0	20.02 0.01	20.01 ± 0.01	0.05
20	20.04 0.01	20.02 -0.01	20.02 -0.01	20.03 0	20.05 0.02	20.03 0	20.03 0	20.02 -0.01	20.02 -0.01	20.03 0	20.02 -0.01	20.03 0	20.03 ± 0.01	0.05
30	30.03 0.01	30.03 0.01	30.01 -0.01	30.02 0	30.02 0	30.01 -0.01	30.01 -0.01	30.03 0.01	30.00 -0.02	30.02 0	30.03 0.01	30.04 0.02	30.02 ± 0.01	0.03
50	49.95 -0.01	49.97 0.01	44.96 0	49.96 0	49.96 0	49.96 0	49.97 0.01	49.97 0.01	49.97 0.01	49.95 -0.01	49.97 0.01	49.98 0.02	49.96 ± 0.01	0.02
100	100.01 0.01	100.01 0.01	99.99 -0.01	99.99 -0.01	100.01 0.01	100.01 0.01	100.02 0.02	100.01 0.01	99.99 -0.01	99.99 -0.01	99.99 -0.01	100.00 0	100.00 ± 0.01	0.01
200	200.01 0	199.98 -0.03	200.04 -0.03	200.00 -0.01	200.02 0.01	200.01 0	200.01 0	200.00 -0.01	199.99 -0.02	200.01 0	200.00 -0.01	200.02 0.01	200.01 ± 0.01	5×10^{-3}
300	300.01 0	300.00 -0.01	300.00 -0.01	300.02 0.01	300.01 0	300.01 0	300.00 -0.01	300.00 -0.01	299.99 -0.02	300.00 -0.01	300.02 0.01	300.02 0.01	300.01 ± 0.01	3×10^{-3}
500	500.01 0.01	499.99 -0.01	499.99 -0.01	500.02 0.02	500.00 0	500.00 0	500.01 0.01	500.00 0	500.00 0	499.99 -0.01	500.02 0.02	500.00 0	500.00 ± 0.01	2×10^{-3}
1000	1000.03 0	1000.04 0.01	1000.00 -0.03	1000.04 0.01	1000.04 0.01	1000.05 0.02	1000.03 0	1000.02 -0.01	1000.02 -0.01	1000.02 -0.01	1000.03 0	1000.01 -0.02	1000.01 ± 0.01	1×10^{-3}
2000	2000.06 0	2000.05 -0.01	2000.07 0.01	2000.09 0.03	2000.08 0.02	2000.08 0.02	2000.09 0.03	2000.05 -0.01	2000.06 0	2000.04 -0.02	2000.06 0	2000.05 -0.01	2000.06 ± 0.01	5×10^{-4}
3000	3000.07 0	3000.06 -0.01	3000.08 0.01	3000.08 0.01	3000.10 0.03	3000.08 0.01	3000.09 0.02	3000.05 -0.02	3000.07 0	3000.05 -0.02	3000.06 -0.01	3000.07 0	3000.07 ± 0.01	3×10^{-4}
5000	5000.02 -0.01	5000.01 -0.02	5000.02 -0.01	5000.05 0.02	5000.05 0.02	5000.04 0.01	5000.05 0.02	5000.01 -0.02	5000.01 -0.02	5000.01 -0.02	5000.02 -0.01	5000.03 0	5000.03 ± 0.01	2×10^{-4}
10000	10000.14 0	10000.15 0.01	10000.14 0	10000.17 0.03	10000.16 0.02	10000.20 0.06	10000.19 0.05	10000.08 -0.06	10000.11 -0.03	10000.11 -0.03	10000.14 0	10000.14 0	10000.14 ± 0.03	3×10^{-4}
20000	20000.14 -0.03	20000.14 -0.03	20000.15 -0.02	20000.15 -0.02	20000.20 0.03	20000.27 0.10	20000.28 0.11	20000.10 -0.07	20000.12 -0.05	20000.15 -0.02	20000.15 -0.02	20000.18 0.01	20000.17 ± 0.06	3×10^{-4}
30000	30000.22 0.01	30000.21 0	30000.19 -0.02	30000.26 0.05	30000.23 0.02	30000.21 0	30000.26 0.05	30000.14 -0.07	30000.21 0	30000.18 -0.03	30000.22 0.01	30000.27 0.06	30000.21 ± 0.04	1×10^{-4}
Tare Weights	0	0	30000 (0)	20000 (0)	10000 (0)	5000 (0)	3000 (0)	2000 (0)	1000 (0)	500	200	50		

Table 2 - Evaluation of Mettler balance under three modes of taring after each weighing.

Ref. Weight (mg)	Date of Calibration, Balance Weight and Deviation from Mean																		Mean and Standard Deviation, $\bar{x}$, σ (mg) and σ (%)	
	20/11/84	21/11/84	21/11/84	21/ /84	21/11/84	21/11/84	21/11/84	22/11/84	22/11/84	22/11/84	22/11/84	22/11/84	19/11/84	15/11/84	15/11/84	19/11/84	16/11/84	16/11/84		
1	0.99 0.01	0.98 0	0.97 -0.01	0.97 -0.01	1.00 -0.02	0.99 0.01	0.98 0	0.99 0.01	0.98 0	0.97 -0.01	1.01 0.03	0.99 0.01	0.98 0	0.95 -0.01	0.97 -0.01	0.99 0.01	0.99 0.01	1.00 0.02	0.98 ± 0.01	1.02
2	2.00 0	2.02 0.02	2.00 0	2.00 0	2.00 0	1.99 -0.01	2.00 0	2.01 0.01	2.01 0.01	2.00 0	2.00 0	2.01 0.01	2.00 0	1.97 -0.03	1.99 -0.01	2.01 0.01	2.00 0	1.97 -0.03	2.00 ± 0.01	0.50
3	2.98 0.01	2.97 0	2.98 0.01	2.97 0	2.96 -0.01	2.97 0	2.97 0	2.99 0.02	2.97 0	2.98 0.01	2.96 -0.01	2.99 0.02	2.97 0	2.96 -0.01	2.96 -0.01	2.96 -0.01	2.91* -0.06	2.95 -0.02	2.97 ± 0.01	0.36
10	10.03 0	10.03 0	10.03 0	10.04 0.01	10.02 -0.01	10.03 0	10.04 0.01	10.05 0.02	10.03 0	10.03 0	10.03 0	10.04 0.01	10.03 0	10.01 -0.02	10.03 0	10.03 0	10.03 0	10.02 -0.01	10.03 ± 0.01	0.10
20	20.02 0.01	19.99 -0.02	20.03 0.02	20.00 -0.01	20.01 0	20.00 -0.01	20.02 0.01	20.02 0.01	20.00 -0.01	19.99 -0.02	20.01 0	20.02 0.01	20.01 0	20.01 0	20.00 -0.01	20.00 -0.01	20.01 0	20.00 -0.01	20.01 ± 0.01	0.05
30	30.04 0.01	30.03 -0.01	30.02 -0.01	30.03 0	30.05 0.02	30.03 0	30.03 0	30.02 -0.01	30.02 -0.01	30.03 0	30.03 0.01	30.03 0	30.02 -0.01	30.02 -0.01	30.03 0	30.02 -0.01	30.02 -0.01	30.01 -0.02	30.03 ± 0.01	0.05
30	30.03 0.02	30.03 0.02	30.01 0	30.02 0.01	30.02 0.01	30.01 0	30.01 0	30.03 0.02	30.00 -0.01	30.02 0.01	30.03 0.02	30.04 0.03	29.99 -0.02	29.99 -0.02	30.01 0	30.00 -0.01	30.00 -0.01	30.00 -0.01	30.01 ± 0.01	0.03
50	49.95 -0.01	49.97 0.01	49.95 0	49.96 0	49.96 0	49.96 0	49.97 0.01	49.97 0.01	49.97 0.01	49.95 -0.01	49.97 0.01	49.98 0.02	49.97 0.01	49.93 -0.03	49.96 0	49.96 -0.02	49.95 -0.01	49.96 0	49.96 ± 0.01	0.02
100	100.01 0.01	100.01 0.01	99.99 -0.01	99.99 -0.01	100.01 0.01	100.01 0.01	100.02 0.02	100.01 0.01	99.99 -0.01	99.99 -0.01	99.99 -0.01	100.00 0	99.99 -0.01	100.00 0	100.00 0	99.98 -0.02	99.99 -0.01	100.00 0	100.00 ± 0.01	0.01
200	200.01 0	199.98 -0.03	200.04 0.03	200.00 -0.01	200.02 0.01	200.01 0	200.01 0	200.00 -0.01	199.99 -0.02	200.01 0	200.00 -0.01	200.02 0.01	200.02 0	200.01 0	200.01 0	199.99 -0.02	200.01 0	200.00 -0.01	200.01 ± 0.01	5×10^{-3}
300	300.01 0.01	300.00 0	300.00 0	300.02 0.02	300.01 0.01	300.01 0.01	300.00 0	300.00 0	299.99 -0.01	300.00 0	300.02 0.02	300.02 0.02	299.99 -0.01	299.99 -0.01	300.00 0	299.96 -0.04	299.99 -0.01	299.99 -0.01	300.00 ± 0.01	3×10^{-3}
500	500.01 0.01	499.99 -0.01	499.99 -0.01	500.02 0.02	500.00 0	500.00 0	500.01 0.01	500.00 0	500.00 0	499.99 -0.01	500.02 0.02	500.00 0	500.00 0	499.99 -0.01	500.00 0	499.99 -0.01	499.99 -0.01	499.99 -0.01	500.00 ± 0.01	2×10^{-3}
1000	1000.03 0	1000.04 0.01	1000.00 -0.03	1000.04 0.01	1000.04 0.01	1000.05 0.02	1000.03 0	1000.02 -0.01	1000.02 -0.01	1000.02 -0.01	1000.03 0	1000.01 -0.02	1000.05 0.02	1000.02 -0.01	1000.05 0.02	1000.04 0.01	1000.01 0	1000.01 -0.02	1000.03 ± 0.01	1×10^{-3}
2000	2000.06 -0.01	2000.05 -0.02	2000.07 0	2000.09 0.02	2000.08 0.01	2000.08 0.01	2000.09 0.02	2000.05 -0.02	2000.06 -0.01	2000.04 -0.03	2000.06 -0.01	2000.05 -0.02	2000.02 0	2000.07 0	2000.09 0.02	2000.07 0	2000.07 0	2000.08 0.01	2000.07 ± 0.01	5×10^{-3}
3000	3000.07 -0.01	3000.06 -0.02	3000.08 0	3000.08 0	3000.10 0.02	3000.08 0	3000.09 0.01	3000.05 -0.03	3000.07 -0.01	3000.05 -0.03	3000.06 -0.02	3000.07 -0.01	3000.09 0.01	3000.10 0.02	3000.11 0.03	3000.11 0.03	3000.08 0	3000.08 0	3000.08 ± 0.02	7×10^{-3}
5000	5000.02 -0.02	5000.01 -0.03	5000.03 -0.01	5000.05 0.01	5000.05 0.01	5000.04 0	5000.05 0.01	5000.01 -0.03	5000.01 -0.03	5000.01 -0.03	5000.02 -0.02	5000.03 -0.01	5000.08 0.04	5000.08 0.04	5000.09 0.05	5000.06 0.02	5000.04 0	5000.04 0	5000.04 ± 0.02	4×10^{-3}
10000	10000.14 -0.02	10000.15 -0.01	10000.16 -0.02	10000.17 0.01	10000.16 0	10000.20 0.04	10000.19 0.03	10000.08 -0.08	10000.11 -0.05	10000.11 -0.05	10000.14 -0.02	10000.16 -0.02	10000.26 0.08	10000.23 0.07	10000.24 0.08	10000.21 0.05	10000.14 -0.02	10000.17 0.01	10000.16 ± 0.05	5×10^{-3}
20000	20000.14 -0.07	20000.14 -0.07	20000.15 -0.06	20000.15 -0.06	20000.20 -0.01	20000.27 0.06	20000.28 0.07	20000.10 -0.11	20000.12 -0.09	20000.15 -0.06	20000.15 -0.06	20000.18 -0.03	20000.38 0.17	20000.33 0.12	20000.38 0.17	20000.32 0.11	20000.20 -0.01	20000.22 0.01	20000.21 ± 0.09	4×10^{-3}
30000	30000.22 -0.07	30000.21 -0.08	30000.19 -0.10	30000.26 -0.03	30000.23 -0.06	30000.31 -0.08	30000.26 -0.03	30000.14 -0.15	30000.21 -0.08	30000.18 -0.11	30000.22 -0.07	30000.27 -0.02	30000.55 0.26	30000.48 0.19	30000.54 0.25	30000.44 0.15	30000.29 0	30000.31 0.02	30000.29 ± 0.12	4×10^{-3}
Tare Weights	0	0	30000 (0)	20000 (0)	10000 (0)	5000 (0)	3000 (0)	2000 (0)	1000 (0)	500	200	50	0	0	100	0	0	100		

* Results rejected for $\bar{x}$ and σ determination.

Table 3 - Comparison of nominal weights and quoted tolerances with apparent weights of Class S calibration weights.

Nominal Mass (mg)	NBS Tolerance Class S (mg)	Tests 1-12 Mean Mass (mg)	Tests 1-18 Mean Mass (mg)	Cahn Electro Mean Mass (mg)
1	0.014	0.98	0.98	0.97
2	0.014	2.00	2.00	1.99
3	0.014	2.97	2.97	2.96
10	0.014	10.03	10.03	10.02
20	0.010	10.01	20.01	19.99
20	0.014	10.03	20.03	20.00
30	0.014	30.02	30.01	30.00
50	0.014	49.96	49.96	49.94
100	0.025	100.00	100.00	99.99
200	0.025	200.01	200.01	(199.99)
300	0.025	300.01	300.00	
500	0.025	500.00	500.00	
1000	0.054	1000.03	1000.03	
2000	0.054	2000.06	2000.07	
3000	0.054	3000.07	3000.08	
5000	0.054	5000.03	5000.04	
10000	0.074	10000.14	10000.16	
20000	0.074	20000.17	20000.21	
30000	0.074	30000.21	30000.29	

for 50% of the 1 mg to 30 g range. However, there is reasonable agreement between the AE 163 and the Cahn Electrobalance. This suggests that the calibration weights may have deteriorated in 18 years of use.

Up to 10 g the deviation about the nominal weight is random and cannot be a fluctuation of the balance. The standard deviation about each mean weight for the balance was 0.01 mg. This demonstrates that the unit weighs consistently throughout its range. The linearity of the AE 163 is determined through regression analyses. These have been performed over the whole weighing range, 0-30 g, also 0-200 mg, against the nominal and mean weights, and for both Tests 1-12 and 1-18. The regression analyses results as listed in Table 4 are gradient of line (ideally 1), intercept of line (ideally 0), the Standard Error of points away from the line and the overall correlation coefficient of points to the regression line.

All regression lines have excellent correlation, the gradients are virtually unity and the intercept values are small. On these parameters it is difficult to establish which line is best. The Standard Errors are more discriminating. From these values it is apparent that using means rather than the nominal weights produced the best line of fit. This is understandable on viewing the deviation distributions in Fig. 2; the frequency distribution of (x-nominal) is skewed to the positive. However, the $(x-\bar{x})$ distributions tend more to a normal distribution as may be expected.

Comparing the 'mean' regression lines it is apparent that the quality of the lines deteriorates with: increasing weight range, and on including Tests 13-18. Thus, the repeated taring to zero between weighing, as in tests 1-12, produces the most consistent results.

The deterioration with increasing weight becomes more apparent in Fig. 3 which shows how the Standard Error varies with the inclusion of each nominal weight for Tests 1-12. Once established a Standard Error, less than

Table 4 - Regression analyses of Test Series I on AE 163

Weight Standard	Tests	Weight Range (mg)	Gradient	Intercept (mg)	Standard Error (mg)	Correlation Coefficient (%)
Quoted	1-12	0-200	1.000012	0.002296	0.024106	99.9999
"	"	0-30000	1.000008	0.010634	0.032675	100.0000
'Mean'	1-12	0-200	0.999975	0.002805	0.010850	100.0001
"	"	0-30000	1.000000	0.001067	0.019966	100.0001
Quoted	1-18	0-200	1.000025	-0.001799	0.025450	100.0000
"	"	0-30000	1.000010	0.007344	0.046656	100.0001
'Mean'	1-18	0-200	0.999986	-0.000076	0.012720	100.0000
"	"	0-30000	1.000000	-0.000530	0.038436	100.0000

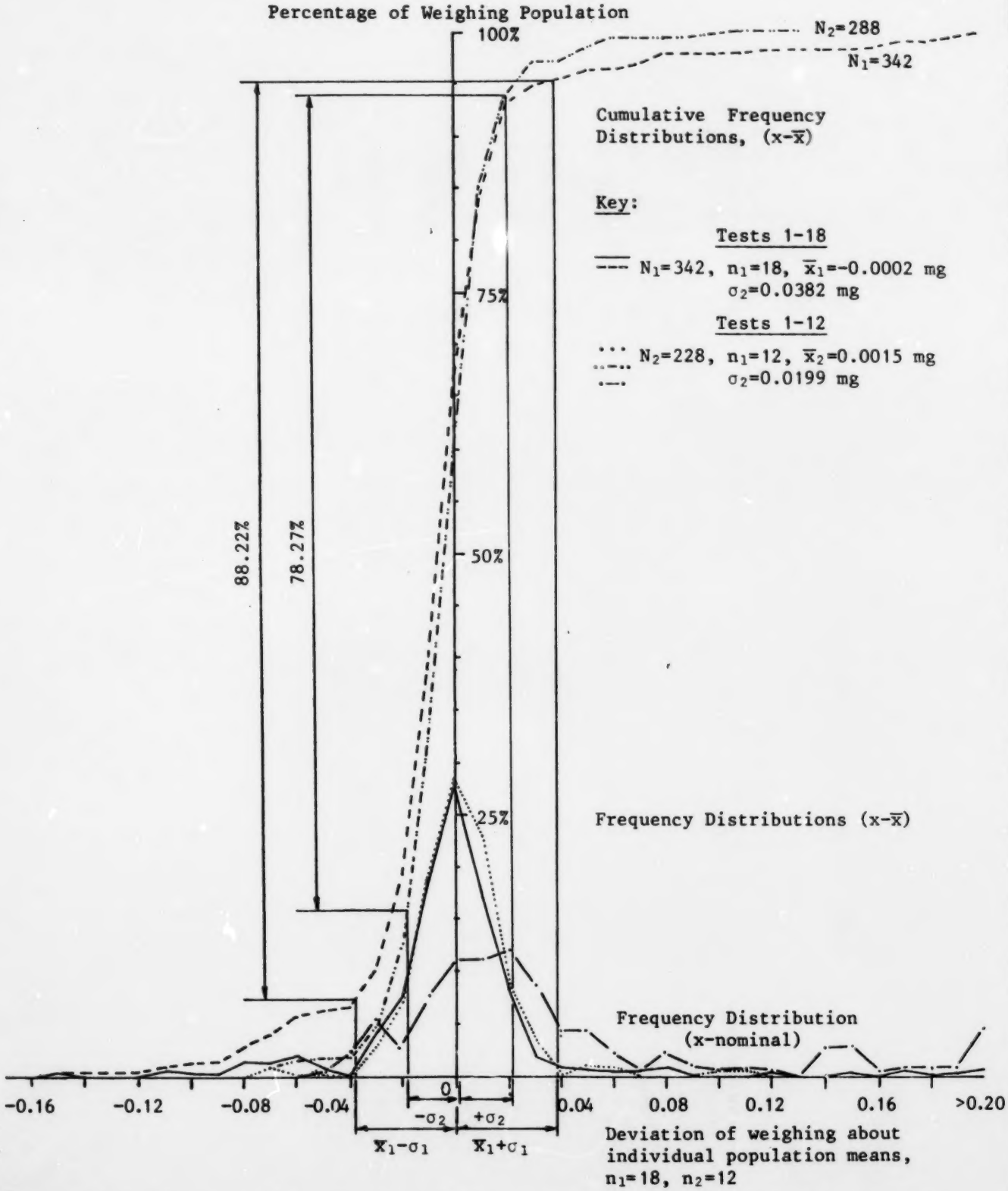

Fig. 2 - Frequency distributions $(x-\bar{x})$ and $|x-\bar{x}|$ of weighing deviations using a Mettler AE 163 electronic balance, weighing range 1 mg to 30 g.

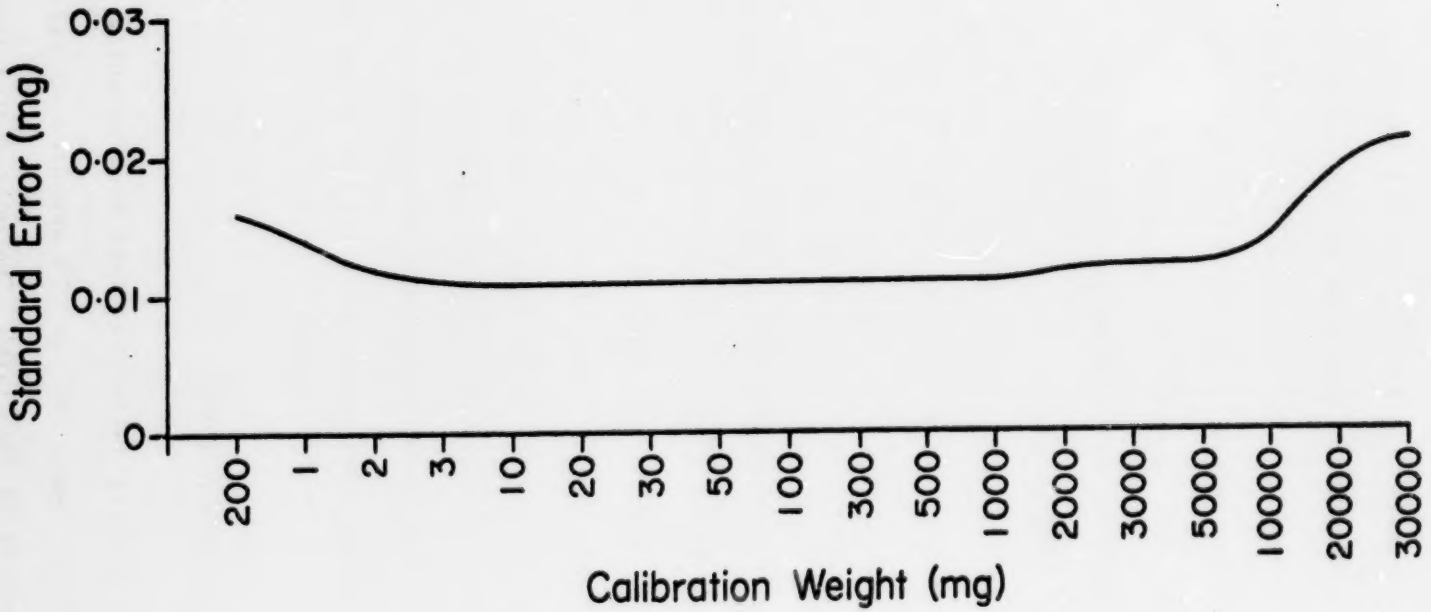

Fig. 3 - Progression of Standard Error on increasing weighing range.

± 0.012 mg, is consistent to 5000 mg, and ± 0.019 mg to 20,000 mg.

TEST SERIES II - COMPARISON OF BALANCES

Three balances were compared; the AE 163, the Cahn Electrobalance and the Mettler Gram-atic. Each balance was used according to instrument instructions to gain optimum results. Two values were obtained for each of three calibration weights and ten reference weights of 200 mg and below. The balances were compared against each other and against the nominal weights and apparent weights for Test Series I, for each weight. The analysis of these results is given in Table 5. In this table, the manual Gram-atic balance is the least consistent. This is apparent in the individual readings and its effects on the mean and Standard Deviation under 'All Balances'. The 'Agreement' in Table 5 is whether the mean value lies within the Standard Deviation of the apparent weight.

The two electronic balances showed good agreement with each other, their standard deviations being small.

The data from this test series were subjected to linear regression analysis. As with Test Series I, all regression lines were reasonably consistent, the only method of differentiating being by Standard Error. The best correlation etc., was for the electronic balances against the apparent weights of Test Series I, and they also compare very favourably with their results for the same weight range 0-200 mg of Tests 1-12 as given below in Table 6.

CONCLUSIONS

The Mettler AE 163 is ideally suited for dust mass weighing; it is quick, and has a wide operating range, 0-31 g. It measures consistently throughout this range irrespective of the 'tare'. The only factor that will

Table 5 - Comparison of three balances in the weighing range 1-200 mg.

Nominal Weight (mg)	Apparent Wt. Test Series I (mg)	(S.D)	Electronic Balances: Mettler AE 163 A (mg)	B (mg)	Mean (mg)	Agreement	Cahn Electrobalance A (mg)	B (mg)	Mean (mg)	Agreement	Manual Balance Gram-atic A (mg)	B (mg)	Mean (mg)	Agreement	All Balances $\bar{x}$ (mg)	σ (mg)	Agreement	Electronic Balances $\bar{x}$ (mg)	σ (mg)	Agreement
200	Not taken on		199.98	199.92	199.90		(199.99	199.99)			200.07	199.93	200.00		199.95	0.03				
20	Calibration		19.99	19.99	19.99		19.98	19.97	19.97		20.07	20.00	20.03		20.00	0.04		19.98	0.01	
2	Weights		2.00	1.96	1.98		2.00	1.99	1.99		1.12	2.08	2.10		2.02	0.06		1.99	0.02	
200	200.01	0.01	200.01	200.01	200.01	✓					200.02	200.05	200.03	X	200.02	0.02	X			
100	100.00	0.01	100.04	100.01	100.02	X	99.99	100.00	99.99	✓	100.00	99.96	99.98	X	100.00	0.03	✓	100.01	0.02	✓
50	49.46	0.01	49.95	49.97	49.96	✓	44.94	49.94	49.94	X	49.98	49.94	49.91	X	49.94	0.03	X	49.95	0.01	✓
30	30.02	0.01	30.03	30.01	30.02	✓	30.00	30.00	30.00	X	29.96	30.02	29.99	X	30.00	0.02	X	30.01	0.01	✓
20	20.03	0.01	20.01	20.02	20.01	X	20.01	20.00	20.00	X	20.00	20.05	20.02	✓	20.01	0.02	X	20.01	0.01	X
20	20.01	0.01	20.02	20.02	20.02	✓	19.98	19.98	19.98	X	19.98	20.04	20.01	✓	20.00	0.02	✓	20.00	0.02	✓
10	10.03	0.01	10.03	10.05	10.04	✓	10.02	10.01	10.01	X	10.04	10.07	10.05	X	10.04	0.02	✓	10.03	0.02	✓
3	2.97	0.01	2.98	2.97	2.97	✓	2.96	2.96	2.96	✓	2.75	2.96	2.85	X	2.93	0.08	X	2.97	0.01	✓
2	2.00	0.01	2.00	1.98	1.99	✓	1.99	1.99	1.99	✓	1.93	2.04	1.98	X	1.99	0.03	✓	1.99	0.01	✓
1	0.98	0.01	0.98	0.98	0.98	✓	0.97	0.97	0.97	✓	0.94	1.04	0.99	✓	0.98	0.01	✓	0.97	0.01	✓

Regression analysis against apparent weight:	Gradient	0.000842	0.999891
	Intercept	0.015020	0.009388
	Correl. Coeff	0.999999	1.000000
	Standard error	0.037533	0.014014
Regression analysis against nominal weight:	Gradient	0.000895	0.999909
	Intercept	0.014690	0.008742
	Correl. Coeff	0.999999	1.000000
	Standard error	0.47781	0.026456

Table 6 - Test Series I and II comparison over 1-200 mg range

	Gradient	Intercept	Correlation	Standard Error
Test Series I				
Tests 1-12, 1-200 mg	0.999975	0.002805	100.0001	0.010850
Test Series II				
Electronic Balances	0.999891	0.009388	100.0000	0.014014

affect its accuracy, apart from environment and vibration is failure to tare to zero before each weighing-in.

The accuracy and precision of the Mettler AE 163 determined in this extensive testing and analysis are:

i) Linearity of range: 0-1 g, $\pm$ 0.011 mg

0-10 g, $\pm$ 0.015 mg

0-30 g, $\pm$ 0.021 mg

ii) Standard Errors by range: 0-1 g, $\pm$ 0.01 mg

1-10 g, $\pm$ 0.03 mg

10-30 g, $\pm$ 0.06 mg

iii) Standard Agreement with Cahn Electrobalance, range

0-200 mg, $\pm$ 0.02 mg